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Performance Comparison of Golden and Silver code for STBC MIMO system

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Abstract
Multiple Input Multiple Output (MIMO) becomes henceforth a vital component of wireless communication systems, widespread standards have implemented it since the need of higher capacity of the channel increased. MIMO systems provide an imposing supply in terms of reliability and coverage allowing better spatial diversity by using multiple antennas at both the transmitter and the receiver sides.
In this paper, we focus on diversity coding; we set up 2 space time block codes (STBC) namely: Golden code and Silver code in MIMO communication channel with 2Tx 2Rx, the results simulation of the system model proposed present the calculation of the bit error rate (BER) according to the signal to noise ratio (SNR) of the system. Obtained results show convincing values of BER at high SNR and a comparison is made for both golden and silver code under 4- QAM modulation.
Keywords: *MIMO, STBC, Silver code, Golden code, ML Decoding, Sphere Decoder.*

1. Introduction
Despite all the progress of wireless communication channel have been made, there are many gaps to fill in order to meet users expectations of higher data rate and performance enhancement
Within this framework, MIMO system was applied as an essential element in IEEE 802.11n (Wi-Fi), IEEE 802.11ac (Wi-Fi), HSPA+ (3G), WiMAX (4G), and Long Term Evolution (4G). as well to power-line communication (PLC) for 3-wire installations as part of ITU G.hn standard and Home Plug AV2 specification.
The power of MIMO relies on using antennas in the transmitter denoted by Tx and the receiver denoted by Rx, Beamforming Tx and Rx ensure gain for diversity and multiplexing.
STBC are mostly adopted in MIMO channel, due to their abilities to transmit multiple copies of a data stream across a number of antennas and to exploit the various received versions of the data to improve the reliability of data-transfer. The fact that the transmitted signal must traverse a potentially difficult environment with scattering, reflection, refraction and so on and may then be further corrupted by thermal noise in the receiver means that some of the received copies of the data will be 'better' than others. This redundancy results in a higher chance of being able to use one or more of the received copies to correctly decode the received signal. In fact space time coding combines all the copies of the received signal in an optimal way to extract as much information from each of them as possible.
In practical terms, Golden code and Silver code represents two schemes of STBC besides the widespread Alamouti, having the same characteristics such as full rank and full diversity;
Some recent researches have treated this topic from different aspect, in [1] a proposed full-rate integer STBCs with reduced number of bits at the encoder and low PAPR values. And has shown that the reduction in the number of processor bits is significant for small MIMO channels, while in [2] authors Proposed STBC scheme has outperformed both the Silver STBC and
Alamouti STBC schemes in both frequency flat and frequency selective channels, beside that Proposed
STBC scheme has a lower value of Peak to Average Power Ratio (PAPR) compared to Silver STBC scheme. Thus the Proposed STBC has outperformed the Silver STBC in terms of both Symbol Error Rate (SER) and PAPR.
In [3], an investigation of the STBC was considered and it has been observed that the Golden code is better than all other considered for their proposed system with and without OFDM calculating the SER.
A good comparison between Alamouti and Golden code was done in [4] where authors deduce that performance of the MIMO system is affected by QAM constellation points. The performance is reduced as the number of constellation mapping points increased from 4 to 16 point and the Alamouti code is the best option when 2 Transmission antennas and 2 Receiver antennas (4- QAM) are considered, with also they prove that Golden code at 4-QAM for 2Tx 2Rx brings better values of BER at low SNR rather than 2Tx 1Rx.
Moreover, in [5] some researches have investigated how to achieve the low-complexity decoding and the highest possible diversity to improve the transmission quality for space-time codes and in [6] analyses the performance of Zero forcing and MMSE equalizer for MIMO wireless channels. In [7], has been investigated the bit error rate

performance characteristics of MIMO system using channel estimation techniques. Channel estimation techniques consists of linear and nonlinear detectors or equalizers which aid in the elimination of Inter Symbol Interference (ISI) thus improving overall performance to analyze the BER of the designed system. For [8] the performance comparison of turbo and silver code shows the elimination of error and provide spectral efficiency to the system. The capacity of MIMO was improved into certain level. The scattering problem was also eliminated. But the comparison turbo code shows the better performance than the silver code. The turbo code based MIMO is the best way to achieve the best performance.

This paper presents the calculation of the BER according to the SNR for the MIMO system using Golden Code and Silver code under different QAM constellation point, the simulation is done using MATLAB Software, and is organized as follows:

After this brief introduction, section 2 represents the MIMO STBC system, process of Silver code and Golden code are exhaustively displayed, in section 3 the simulation results and the discussion, section 4 for the conclusion with some directions for future works, section 5 embodies the references, and finally a short biographies of the authors .

2. STBC-MIMO

2.1 Silver code

The Silver Code is a fast-decodable space-time block code for 2 transmit and 2 receive antennas.

Properties

- Full-rank: the determinant of the difference of 2 code words is always different from 0.
- Full-rate: the four degree of freedom of the system is used, which allows to send 4 information symbols.
- Non-vanishing determinant for increasing rate the minimum determinant is 1/7, slightly smaller than that of the Golden code.
- Cubic shaping: each layer is carved from a rotated version of Z[i]^2.
- The spectral efficiency is 2log2 (Q) bits/s/Hz for Q-QAM.

Encoding Silver code

The figure (1) below shows a 2*2 MIMO Channel:

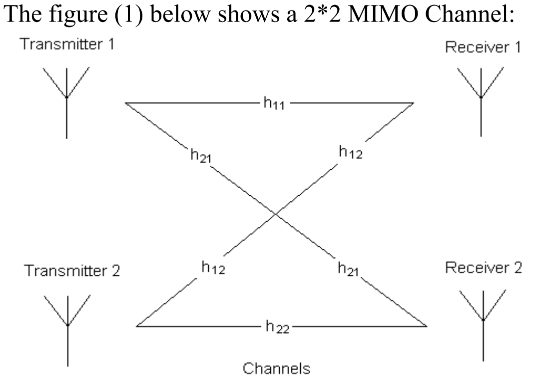

Figure 1 :2Tx 2Rx MIMO Channel

The channel model considered is $Y = H\ X + N$, where $H = \{hij\}$ is the 2x2 channel matrix with complex impulse responses from jth transmitter to ith receiver.

Where X denotes transmitted symbol Matrix and N denotes the 2x2 complex Gaussian noise matrix. The code words X of the Silver Code are 2x2 complex matrices of the following form

$$X = X_a(s_1, s_2) + T X_b(z_1, z_2)$$

Where X_a and X_b take Alamouti structure

$$X_a(s_1,s_2) = \begin{bmatrix} s_1 & -s_2^* \\ s_2 & s_1^* \end{bmatrix} \text{ and } X_b(z_1,z_2) = \begin{bmatrix} z_1 & -z_2^* \\ z_2 & z_1^* \end{bmatrix}$$

$$\begin{bmatrix} z_1 \\ z_2 \end{bmatrix} = \frac{1}{\sqrt{7}} \begin{bmatrix} 1+j & -1+2j \\ 1+2j & 1-j \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \end{bmatrix}$$

And

$$T = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$$

Finally we calculate X as:

$$X = \begin{bmatrix} s_1 + \frac{1}{\sqrt{7}}\left[(1+j)s_3 + (-1+2j)s_4\right] & -s_2^* - \frac{1}{\sqrt{7}}\left[(1-2j)s_3^* + (1+j)s_4^*\right] \\ s_2 - \frac{1}{\sqrt{7}}\left[(1+2j)s_3 + (1-j)s_4\right] & s_1^* - \frac{1}{\sqrt{7}}\left[(1-j)s_3^* + (-1-2j)s_4^*\right] \end{bmatrix}$$

We stack X columnwise to get 4*1 matrix given below:

$$X = \begin{bmatrix} s_1 + \frac{1}{\sqrt{7}}\left[(1+j)s_3 + (-1+2j)s_4\right] \\ s_2 - \frac{1}{\sqrt{7}}\left[(1+2j)s_3 + (1-j)s_4\right] \\ -s_2^* - \frac{1}{\sqrt{7}}\left[(1-2j)s_3^* + (1+j)s_4^*\right] \\ s_1^* - \frac{1}{\sqrt{7}}\left[(1-j)s_3^* + (-1-2j)s_4^*\right] \end{bmatrix}$$

In the above matrix, real and imaginary parts are separated out to get 8*1 matrix given below:

$$X = \begin{bmatrix} \mathrm{Re}(s_1) + \frac{1}{\sqrt{7}}\mathrm{Re}(s_3) - \frac{1}{\sqrt{7}}\mathrm{Im}(s_3) - \frac{1}{\sqrt{7}}\mathrm{Re}(s_4) - \frac{2}{\sqrt{7}}\mathrm{Im}(s_4) \\ \mathrm{Im}(s_1) + \frac{1}{\sqrt{7}}\mathrm{Re}(s_3) + \frac{1}{\sqrt{7}}\mathrm{Im}(s_3) + \frac{2}{\sqrt{7}}\mathrm{Re}(s_4) - \frac{1}{\sqrt{7}}\mathrm{Im}(s_4) \\ \mathrm{Re}(s_2) - \frac{1}{\sqrt{7}}\mathrm{Re}(s_3) + \frac{2}{\sqrt{7}}\mathrm{Im}(s_3) - \frac{1}{\sqrt{7}}\mathrm{Re}(s_4) - \frac{1}{\sqrt{7}}\mathrm{Im}(s_4) \\ \mathrm{Im}(s_2) - \frac{2}{\sqrt{7}}\mathrm{Re}(s_3) - \frac{1}{\sqrt{7}}\mathrm{Im}(s_3) + \frac{1}{\sqrt{7}}\mathrm{Re}(s_4) - \frac{1}{\sqrt{7}}\mathrm{Im}(s_4) \\ -\mathrm{Re}(s_2) - \frac{1}{\sqrt{7}}\mathrm{Re}(s_3) + \frac{2}{\sqrt{7}}\mathrm{Im}(s_3) - \frac{1}{\sqrt{7}}\mathrm{Re}(s_4) - \frac{1}{\sqrt{7}}\mathrm{Im}(s_4) \\ \mathrm{Im}(s_2) + \frac{2}{\sqrt{7}}\mathrm{Re}(s_3) + \frac{1}{\sqrt{7}}\mathrm{Im}(s_3) - \frac{1}{\sqrt{7}}\mathrm{Re}(s_4) + \frac{1}{\sqrt{7}}\mathrm{Im}(s_4) \\ \mathrm{Re}(s_1) - \frac{1}{\sqrt{7}}\mathrm{Re}(s_3) + \frac{1}{\sqrt{7}}\mathrm{Im}(s_3) + \frac{1}{\sqrt{7}}\mathrm{Re}(s_4) + \frac{2}{\sqrt{7}}\mathrm{Im}(s_4) \\ -\mathrm{Im}(s_1) + \frac{1}{\sqrt{7}}\mathrm{Re}(s_3) + \frac{1}{\sqrt{7}}\mathrm{Im}(s_3) + \frac{2}{\sqrt{7}}\mathrm{Re}(s_4) - \frac{1}{\sqrt{7}}\mathrm{Im}(s_4) \end{bmatrix}$$

It also can be factorized as follows:

$$X = \underbrace{\begin{bmatrix} 1 & 0 & 0 & 0 & \frac{1}{\sqrt{7}} & \frac{-1}{\sqrt{7}} & \frac{-1}{\sqrt{7}} & \frac{-2}{\sqrt{7}} \\ 0 & 1 & 0 & 0 & \frac{1}{\sqrt{7}} & \frac{1}{\sqrt{7}} & \frac{2}{\sqrt{7}} & \frac{-1}{\sqrt{7}} \\ 0 & 0 & 1 & 0 & \frac{-1}{\sqrt{7}} & \frac{2}{\sqrt{7}} & \frac{-1}{\sqrt{7}} & \frac{-1}{\sqrt{7}} \\ 0 & 0 & 0 & 1 & \frac{-2}{\sqrt{7}} & \frac{-1}{\sqrt{7}} & \frac{1}{\sqrt{7}} & \frac{-1}{\sqrt{7}} \\ 0 & 0 & -1 & 0 & \frac{-1}{\sqrt{7}} & \frac{2}{\sqrt{7}} & \frac{-1}{\sqrt{7}} & \frac{-1}{\sqrt{7}} \\ 0 & 0 & 0 & 1 & \frac{2}{\sqrt{7}} & \frac{1}{\sqrt{7}} & \frac{-1}{\sqrt{7}} & \frac{1}{\sqrt{7}} \\ 1 & 0 & 0 & 0 & \frac{-1}{\sqrt{7}} & \frac{1}{\sqrt{7}} & \frac{1}{\sqrt{7}} & \frac{2}{\sqrt{7}} \\ 0 & -1 & 0 & 0 & \frac{1}{\sqrt{7}} & \frac{1}{\sqrt{7}} & \frac{2}{\sqrt{7}} & \frac{-1}{\sqrt{7}} \end{bmatrix}}_{\mathbf{G}} \underbrace{\begin{bmatrix} \mathrm{Re}(s_1) \\ \mathrm{Im}(s_1) \\ \mathrm{Re}(s_2) \\ \mathrm{Im}(s_2) \\ \mathrm{Re}(s_3) \\ \mathrm{Im}(s_3) \\ \mathrm{Re}(s_4) \\ \mathrm{Im}(s_4) \end{bmatrix}}_{\mathbf{Z}}$$

X=GZ

G: is the Generator matrix for Silver Code and
Z: is the matrix containing real and imaginary parts of modulated symbols as rows.
This process is general for any linear STBC.
The channel matrix H for any 2 X 2 STBC is a 2 X 2 complex matrix and it can be expanded into an 8 X 8 real matrix given below:

$$H = \begin{bmatrix} \mathrm{Re}(h_{11}) & -\mathrm{Im}(h_{11}) & \mathrm{Re}(h_{12}) & -\mathrm{Im}(h_{12}) & 0 & 0 & 0 & 0 \\ \mathrm{Im}(h_{11}) & \mathrm{Re}(h_{11}) & \mathrm{Im}(h_{12}) & \mathrm{Re}(h_{12}) & 0 & 0 & 0 & 0 \\ \mathrm{Re}(h_{21}) & -\mathrm{Im}(h_{21}) & \mathrm{Re}(h_{22}) & -\mathrm{Im}(h_{22}) & 0 & 0 & 0 & 0 \\ \mathrm{Im}(h_{21}) & \mathrm{Re}(h_{21}) & \mathrm{Im}(h_{22}) & \mathrm{Re}(h_{22}) & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \mathrm{Re}(h_{11}) & -\mathrm{Im}(h_{11}) & \mathrm{Re}(h_{12}) & -\mathrm{Im}(h_{12}) \\ 0 & 0 & 0 & 0 & \mathrm{Im}(h_{11}) & \mathrm{Re}(h_{11}) & \mathrm{Im}(h_{12}) & \mathrm{Re}(h_{12}) \\ 0 & 0 & 0 & 0 & \mathrm{Re}(h_{21}) & -\mathrm{Im}(h_{21}) & \mathrm{Re}(h_{22}) & -\mathrm{Im}(h_{22}) \\ 0 & 0 & 0 & 0 & \mathrm{Im}(h_{21}) & \mathrm{Re}(h_{21}) & \mathrm{Im}(h_{22}) & \mathrm{Re}(h_{22}) \end{bmatrix}$$

2.2 Golden code

Golden Code is a 2×2 algebraic perfect space-time code with unprecedented performance based on the Golden number (1+√5)/2. It is a full-rate, full-diversity Space-Time code for 2 transmits and 2 receive antennas, for the coherent MIMO channel. In this page, we discuss Golden code for 2transmitters-1receiver system (2x1) and 2transmitters-2receivers system (2x2).

Properties

- Full-rank: the determinant of the difference of 2 code words is always different from 0.
- Full-rate: the four degrees of freedom of the system are used, which allows to send 4 information symbols.
- Non-vanishing determinant: The minimum determinant of the Golden Code is 1/5.
- Cubic shaping: each layer is carved from a rotated version of Z[i]^2.
- The spectral efficiency is 2log2 (M) bits/s/Hz.

Encoding Golden code

The MIMO channel for Golden code is the same in figure 1.
The code words X of the Golden Code are 2x2 complex matrices of the following form:

$$X = \frac{1}{\sqrt{5}} \begin{bmatrix} \alpha\,[a+b\theta] & \alpha\,[c+d\theta] \\ i\,\sigma(\alpha)\,[c+d\sigma(\theta)] & \sigma(\alpha)\,[a+b\sigma(\theta)] \end{bmatrix}$$

Where a, b, c and d are the information symbols which can be taken from any M-QAM constellation carved from Z[i].

$$i = \sqrt{-1} \qquad \theta = \frac{1+\sqrt{5}}{2} = 1.618\ldots \text{ (Golden number)}$$

$$\sigma(\theta) = \frac{1-\sqrt{5}}{2} = 1-\theta$$

$$\alpha = 1 + i - i\,\theta = 1 + i\,\sigma(\theta)$$

$$\sigma(\alpha) = 1 + i - i\,\sigma(\theta) = 1 + i\,\theta$$

Using the relation

$$\theta\,\sigma(\theta) = -1 \quad \text{and} \quad \theta + \sigma(\theta) = 1$$

We can rewrite the codeword matrices as:

$$X = \frac{1}{\sqrt{5}} \begin{bmatrix} [1 + i\,\sigma(\theta)]a + [\theta - i]b & [1 + i\,\sigma(\theta)]c + [\theta - i]d \\ [i - \theta]c + [1 + i\sigma(\theta)]d & [1 + i\,\theta]a + [\sigma(\theta) - i]b \end{bmatrix}$$

We stack X column wise to get 4*1 matrix given below:

In the above matrix, real and imaginary parts are separated out to get 8*1 matrix given below:

$$X = \frac{1}{\sqrt{5}} \begin{bmatrix} [1 + i\,\sigma(\theta)]a + [\theta - i]b \\ [i - \theta]c + [1 + i\sigma(\theta)]d \\ [1 + i\,\sigma(\theta)]c + [\theta - i]d \\ [1 + i\,\theta]a + [\sigma(\theta) - i]b \end{bmatrix}$$

In the above matrix, real and imaginary parts are separated out to get 8*1 matrix given below:

$$X = \frac{1}{\sqrt{5}} \begin{bmatrix} \mathrm{Re}(a) - \sigma(\theta)\mathrm{Im}(a) + \theta\,\mathrm{Re}(b) + \mathrm{Im}(b) \\ \sigma(\theta)\mathrm{Re}(a) + \mathrm{Im}(a) - \mathrm{Re}(b) + \theta\,\mathrm{Im}(b) \\ -\theta\,\mathrm{Re}(c) - \mathrm{Im}(c) + \mathrm{Re}(d) - \sigma(\theta)\mathrm{Im}(d) \\ \mathrm{Re}(c) - \theta\,\mathrm{Im}(c) + \sigma(\theta)\mathrm{Re}(d) + \mathrm{Im}(d) \\ \mathrm{Re}(c) - \sigma(\theta)\mathrm{Im}(c) + \theta\,\mathrm{Re}(d) + \mathrm{Im}(d) \\ \sigma(\theta)\mathrm{Re}(c) + \mathrm{Im}(c) - \mathrm{Re}(d) + \theta\,\mathrm{Im}(d) \\ \mathrm{Re}(a) - \theta\,\mathrm{Im}(a) + \sigma(\theta)\mathrm{Re}(b) + \mathrm{Im}(b) \\ \theta\,\mathrm{Re}(a) + \mathrm{Im}(a) - \mathrm{Re}(b) + \sigma(\theta)\mathrm{Im}(b) \end{bmatrix}$$

It also can be factorized as follows:

$$X = \frac{1}{\sqrt{5}} \underbrace{\begin{bmatrix} 1 & -\sigma(\theta) & \theta & 1 & 0 & 0 & 0 & 0 \\ \sigma(\theta) & 1 & -1 & \theta & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -\theta & -1 & 1 & -\sigma(\theta) \\ 0 & 0 & 0 & 0 & 1 & -\theta & \sigma(\theta) & 1 \\ 0 & 0 & 0 & 0 & 1 & -\sigma(\theta) & \theta & 1 \\ 0 & 0 & 0 & 0 & \sigma(\theta) & 1 & -1 & \theta \\ 1 & -\theta & \sigma(\theta) & 1 & 0 & 0 & 0 & 0 \\ \theta & 1 & -1 & \sigma(\theta) & 0 & 0 & 0 & 0 \end{bmatrix}}_{G} \underbrace{\begin{bmatrix} \mathrm{Re}(a) \\ \mathrm{Im}(a) \\ \mathrm{Re}(b) \\ \mathrm{Im}(b) \\ \mathrm{Re}(c) \\ \mathrm{Im}(c) \\ \mathrm{Re}(d) \\ \mathrm{Im}(d) \end{bmatrix}}_{Z}$$

X=GZ

G is the Generator matrix for Golden Code and Z is the matrix containing real and imaginary parts of modulated symbols as rows.

3. SIMULATION ENVIRONMENT

3.1 Sphere Decoder:

The Decoding is performed using Sphere Decoder

To lower the complexity, a new type of decoding method called sphere decoding can be used. The sphere decoding algorithm has near ML performance with reasonably low complexity [9].

The principle of sphere decoding algorithm is to search the closest constellation point to the received signal with in a sphere of some initial radius. If a point is found and if the distance between the centre and the point is less than the radius, the radius is updated to that distance and the process is continued till only one point is left in the sphere. That will be the closest constellation point to the received point [10]. If a point is not found initially, then the sphere radius is incremented and the same process is followed.

Let:
B=HG.
So, Y = BZ + N. where Y is the received matrix.

We perform Gram-Schmidt orthonormalization of the columns of B (QR decomposition of B)
to get B=QR

where R is an upper triangular matrix with positive diagonal elements and Q is a unitary matrix.
Let R = {r ij}.
R (equivalently all the r_{ij}' s) is an input to the algorithm.

Step1: Initialization step: set i=m, $T_{m=0}$, $E_{m=0}$, $d_c = C^I_0$ (current Sphere squared radius).

Step2: (Bounds on X_i)
if d_c<Ti go to step 4,
else

$$A_i(x^m_{i+1}) = \max\left[0, \left\lceil \frac{y'_i - E_i - \sqrt{d_c - T_i}}{r_{i,i}} \right\rceil\right]$$

$$B_i(x^m_{i+1}) = \min\left[Q - 1, \left\lfloor \frac{y'_i - E_i - \sqrt{d_c - T_i}}{r_{i,i}} \right\rfloor\right]$$

And set:

$$x_i = A_i(x^m_{i+1}) - 1 .$$

Step3: (Natural spanning of the interval)

$I_i(x^m_{i+1})$ $X_i = X_i + 1$;

If $x_i < B_i(x^m_{i+1})$ go to step 5 , else go to step 4.

Step4: (Increase i move one level down)
if i=m
terminate
else
Set i=i+1; and go to step 3;

Step5: (decrease i move one level up)
If i>1 then

$$\text{Let } E_{i-1} = \sum_{j=1}^{m} r_{i-1,j}\, x_j$$

$$T_{i-1} = T_i + \left| y'_i - E_i - r_{i,i}\, x_i \right|^2 ,$$

Let i=i-1 and go to step 2;

Step6: (A valid point is found)

Compute

$$\hat{d} = \left| y'_1 - E_1 - r_{1,1}\, x_1 \right|^2$$

If $\hat{d} < d_c$ Let $d_c = \hat{d}$, save $\hat{x} = x$

And update the upper boundaries.

$$B_t(x^m_{t+1}) = \min \left[Q-1 , \left\lfloor \frac{y'_t - E_t - \sqrt{d_c - T_t}}{r_{t,t}} \right\rfloor \right]$$

For all t=1,……,m Go to step 3

3.2 ML Decoding:

The best performance is given by the brute force ML decoder which searches for the matrix X which minimizes the overall noise power.i.e:
.ML decoder computes an estimate of the transmitted matrix as:

$$\hat{X} = \arg\min_{X} \|Y-HX\|^2$$

It should be noted that even for Golden code the Sphere decoder can be used for its decreased complexity.
The simulation of 2*2 MIMO channel using 2Tx 2Rx according to the parameters of the table below:

Parameters	Specification
Rx	2
Tx	2
Modulation type	4-QAM
STBC	Silver and Golden
Bit rate	1Mbps
Bandwidth	5Mhz
Channel	Rayleigh Fading Channel

4. SIMULATION RESULTS

The figure 2 below shows the BER of the Golden STBC for 2*2 MIMO channel using the ML Decoder:

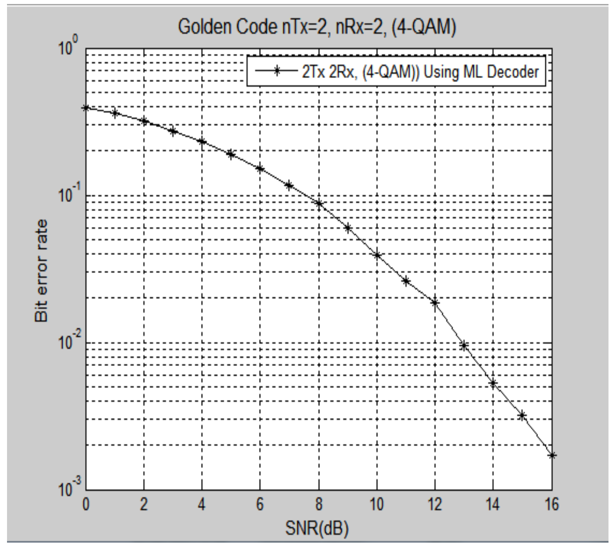

Figure 2: BER performance of 2*2 MIMO for Golden code using ML Decoder

While in the figure 3 we present the same scenario but the Sphere decoder instead of ML:

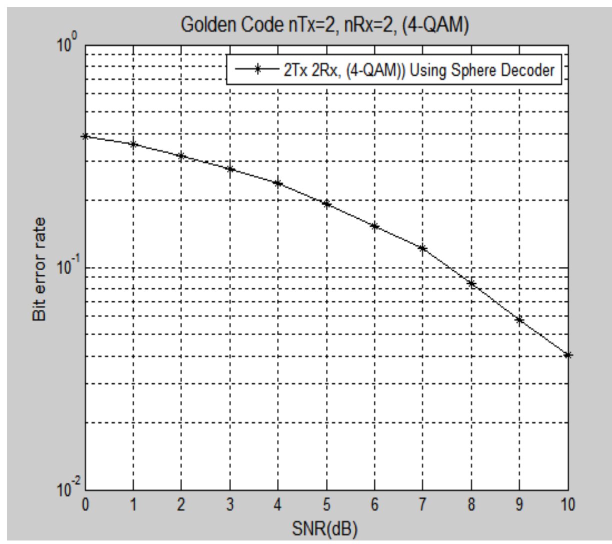

Figure 3: BER performance of 2*2 MIMO for Golden code using Sphere Decoder

We present in figure 4 the BER performance of the same system but using Silver code as the STBC, Silver code can be decoded using Sphere decoder, which is less complex than other decoders:

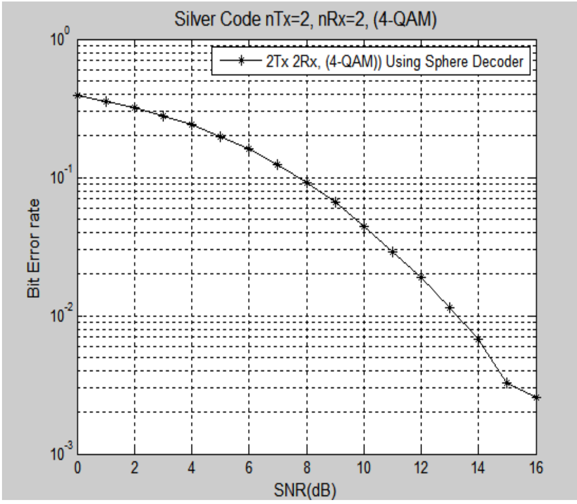

Figure 4: BER performance of 2*2 MIMO for Silver code using Sphere Decoder

5. CONCLUSION

From the results displayed above, we have compared the Golden code and Silver code for 2Tx 2Rx MIMO channel. The first conclusion it can be reached is that the BER of the system has the best value for Golden code using the ML Decoder.

A second point to that caught attention is that the use of the Sphere decoder remains less complex than ML Decoder but in terms of performance, ML allows for system greater efficiency which is clearly demonstrated from the behaviour of the BER over different values of SNR.

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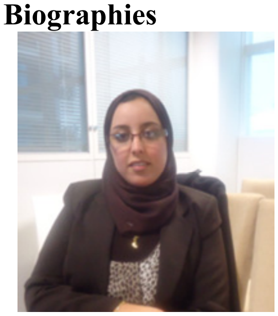
Biographies



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